Analysis of pressure-driven and diffusion-based gas filling methods of Antiresonant Hollow-Core Fibers

Piotr Bojęś[1], Paweł Kozioł[1], Ziemowit Malecha[2], Piotr Jaworski[1] and Karol Krzempek[1]

[1]Faculty of Electronics, Photonics and Microsystems, Wroclaw University of Science and Technology, Wybrzeże Wyspiańskiego 27, 50-370 Wrocław, Poland
[2]Faculty of Mechanical and Power Engineering, Wroclaw University of Science and Technology, Wybrzeże Wyspiańskiego 27, 50-370 Wrocław, Poland

In laser gas spectroscopy, the absorption cell, which extends the interaction path length between the gas and the light, is one of the most important parts of the vast majority of gas detection systems. Commonly used multi-pass cells, due to their size and relatively large gas sample volume required to fill them, have limited applicability in some measurement systems. An alternative type of absorption cells are those based on the hollow-core fibers (HCFs). Among many types of HCFs, the so-called Antiresonant Hollow-Core Fibers (ARHCFs) have been shown to provide almost single-mode, low-loss light transmission even in the mid-infrared range, and work on small volumes of measured samples. One of the main problems in the use of the ARHCFs in sensing setups is the method of efficient filling them with the target gas sample. The time required to fill the ARHCF with the measured gas strictly depends on the fiber length, core size and selected gas filling approach. Here, we would like to analyze two main methods for filling the nodeless type of ARHCF: pressure-driven flow method and diffusion-based method. In the first one, fiber filling requires generating a difference in pressure between the inlet of the fiber and the outlet. Due to this, the gas starts to flow in the direction of lower pressure, and the velocity of flow is determined by the gradient of gas pressure in the flow channel (hollow region of the fiber). In most cases, gas behavior for continuous flow can be predicted by using the Navier-Stokes equations-based flow model. In case of diffusive exchange of gases, one observes natural migration of measured gas molecules from a region of higher concentration to a lower, without the application of any external force. In case of diffusive exchange, the second Fick law is sufficient to approximate the gas exchange time between the fiber core and the outside environment. In this work, we will compare the abovementioned gas filling methods of ARHCFs based on the set of simulations and experimental analysis. In our work, we used two different lengths of 84 µm- core nodeless ARHCF: 14.74 m for pressure-driven method and 1.25 m for diffusion-based method. The gas exchange dynamics obtained in experiments were compared with the simulated flow characteristics. For simulations, the OpenFOAM® package was used with two solvers: reactingFOAM for pressure-driven flow and simpleFOAM for diffusive exchange. This allowed us to analyze the advantages and disadvantages of both filling techniques and to show that the choice of the appropriate filling method should depend on the final application area of the ARHCF-based gas sensor.

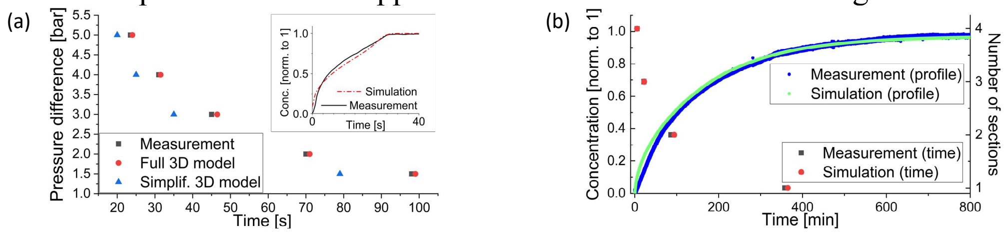

Fig. 1. (a) Filling time of 14.73 m ARHCF via pressure-driven flow method for various pressure differences, with additional filling profile for 2 bar of overpressure in the inset. (b) Diffusion-based simulated (green trace) and measured (blue trace) filling profiles of non-processed and both-end opened 1.25 m ARHCF .The filling times for the same ARHCF with microfabricated additional holes in the structure are presented as black (measured) and red (simulated) dots.